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AIR FORCE

HUMAN RESOURCES

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EXPERT ESTIMATE METHOD OF GENERATING MAINTENANCE AND MANPOWER DATA FOR PROPOSED AIR FORCE SYSTEMS: EVALUATION

By

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Final Report

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NOTICE

This final report was submitted by Systems Research Laboratories, Inc., 2800 Indian Ripple Road, Dayton, Ohio 45440, under contract F33615-77-C-0060, project 1124, with Advanced Systems Division, Air Force Human Resources Laboratory (AFSC), Wright-Patterson Air Force Base, Ohio 45433. Mr. Robert N. Deem was the Contract Monitor for the Laboratory.

This technical report has been reviewed and is approved for publication.

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The objectives of this study were to exercise an expert estimate method of generating maintenance and manpower data for new systems, to determine the accuracy of the estimated data, to evaluate a prototype guide describing the expert estimate method, to collect cost data for implementing the method, and to prepare a users manual for the expert estimate method. Seventy Air Force technicians having one of three ground radar Air Force Specialty Codes participated as expert estimators. These technicians estimated maintenance, manpower, and training requirements for a new operational ground radar system. The estimators had no experience on the radar system and used only an early design phase engineering description of the system as the basis for their estimates. The accuracy of the estimated data was determined by comparing the estimates with the operational data collected on the radar

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Item 19 (Continued)

support equipment
task difficulty
training time
troubleshooting difficulty

Item 20 (Continued)

system. Results indicate that technicians can estimate maintenance task time, crew size, skill level, career field/AFSC requirements, and training times with acceptable levels of accuracy. The method also produced derived person-hour estimates. Estimates of support equipment requirements, the distribution of maintenance tasks, and derived person-hours for troubleshooting and specific off-equipment maintenance tasks were not accurately estimated. The prototype users guide recommendations were generally supported in the areas of engineering description package and questionnaire preparation, qualifications of estimators, and analyses of estimated data. The person-hours cost data indicated that the minimum number of raters should be increased to 25, and that the expert estimate method seems to be an inexpensive and rapid method of obtaining maintenance manpower data. A revised users guide (Technical Report AFHRL-TR-79-80) was prepared on the basis of the study results.

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SUMMARY

Background

The human resources requirements for new Air Force systems represent a substantial portion of system ownership costs. These requirements should, therefore, be assessed early in system design stages to ensure optimal use and lowest possible costs of human resources. Appropriate data, however, are not often available in the early stages of the system design process. Recent studies have suggested that estimates of maintenance, manpower, and training requirements for Air Force systems in the early design stages could be made by technicians with maintenance experience on similar, currently operational systems.

Objectives

The objectives of the study were to exercise an expert estimate method of generating maintenance and manpower data for new systems, to determine the accuracy of this estimated data, to collect cost data for implementing the method, to evaluate a prototype users guide describing the method, and to prepare a revised users guide for the expert estimate method.

Approach

Using only an early design phase description of a ground-based radar system, estimates were made by maintenance technicians of maintenance, manpower, and training requirements for that system. These estimates were made following the procedures and recommendations contained in a prototype users guide for collecting expert estimates. The accuracy of the estimates was determined by comparing the estimated data with operational data obtained either from Air Force maintenance records or from maintenance experts working with the radar system.

Based on the recommendations in the prototype guide, an early design phase engineering description of the AN/TPS-43(E) radar system was prepared, consisting of a basic engineering description package and a supplement to the basic package. A questionnaire was designed to collect estimates of maintenance task times, crew size, skill level, percent of maintenance task occurrences, troubleshooting difficulty, career field/Air Force Specialty Code (AFSC) requirements, training times and support equipment requirements. Seventy radar maintenance technicians from the 303X1 ASFC (Air Traffic Control Radar), the 303X2 AFSC (Aircraft Control and Warning Radar), and the 303X3 AFSC (Automatic Tracking Radar) with varying levels of maintenance experience participated as expert estimators. The technicians were located at five Air Force bases. The technicians provided their maintenance background data, rated their confidence in their estimates, indicated the relative importance of the data sources upon which they based their estimates, and indicated the effect on their estimates of the supplemental engineering data.

The thrust of the analysis was to determine (a) the accuracy of the estimates, (b) how the estimated data were affected by qualifications of estimators, (c) the amount of engineering detail which should be presented in the engineering description package, (d) the kinds of human resources data which can be estimated, (e) the types of information that technicians used to make their estimates, and (f) the confidence technicians placed in their estimates. Cost data for applying the technique were tracked and examined. Critical evaluations of the prototype guide itself were obtained from Air Force manpower professionals. Findings from all phases of the effort were incorporated in a revised users guide for the expert estimate method.

Results and Conclusions

A comparison of the estimates with the operational data indicates that crew size, skill level, troubleshooting difficulty, career field/AFSC requirements, and training times can be satisfactorily estimated. Acceptable derived estimates were produced for maintenance person-hours. The data items that were not satisfactorily estimated were percentage of maintenance task occurrences, support equipment requirements, and derived person-hour estimates for troubleshooting and specific off-equipment maintenance tasks.

Recommendations in the prototype users guide regarding the form and content of the engineering description package and the form and content of the data collection questionnaire were supported. Recommendations in the users guide regarding the qualifications of the estimators were generally supported. Technician estimators should hold an AFSC which is the same as or similar to the AFSC proposed for the new system. All estimators should have attained a skill level of at least 5 in their AFSC. However, the cost data indicated that increasing the recommended 10 estimators to 25 incurred only a small percentage increase in overall person-hour costs.

Estimators reported that they were slightly less than "Confident" about their estimates, that any given estimate was based more on their maintenance experience (67 percent) than on the engineering data provided (33 percent), and that the supplemental engineering data had no effect on their estimates.

Cost data reflected that the number of person-hours required for an effort similar in scope to the current study would be 657.5 person-hours. Travel and material costs were recognized but not estimated because of the potential variations in travel and material requirements and costs. No similar data-generating methods could be identified for cost-comparison purposes.

Manpower professionals evaluated the prototype guide in terms of clarity and content. These evaluation comments, along with the findings of the application of the expert estimate method to the radar system, were the bases upon which revisions were made to the guide.

PREFACE

This study was performed by Systems Research Laboratories, Inc. (SRL), 2800 Indian Ripple Road, Dayton, Ohio. Technical direction was provided by the Advanced Systems Division, Air Force Human Resources Laboratory (AFHRL), Wright-Patterson Air Force Base, Ohio.

The AFHRL support was provided under Project 1124, Human Resources in Aerospace System Development and Operations; Dr. Ross L. Morgan was the Project scientist and Mr. Robert N. Deem was the Work Unit scientist.

SRL performed the research under Contract F33615-77-C-0060 with Mr. Daniel W. Sauer as Principal Investigator.

The authors wish to acknowledge the many individuals who contributed to this effort. Appreciation is extended to Aerospace Defense Command (ADC) personnel in the 754th Radar Squadron at Port Austin AFS, Michigan; and to Air Force Communications Service (AFCS) personnel in the 1972nd Communications Squadron, Eglin AFB, Florida; the 2179th Communication and Installation Group, Patrick AFB, Florida; and the 2046th Communication and Installation Group, Wright-Patterson AFB, Ohio. Appreciation is also extended to Tactical Air Command (TAC) personnel in the 56th Combat Support Squadron at Avon Park Air Force Range, Florida, and to personnel in the 75th Tactical Control Flight and the 728th Tactical Control Squadron at Eglin AFB, Florida. Special appreciation is extended to Maj. C. McGeehee and Capt. R. Lessard of Headquarters TAC for their assistance in obtaining data on the AN/TPS-43(E) radar system and coordination of visits to TAC units. Special appreciation is also extended to CMSGT May, Headquarters ADC, and to Mr. Paul Goldberg, Headquarters AFCS, for their efforts in coordinating data collection visits to their respective command's units.

Special thanks are extended to the following individuals for their efforts in evaluating the prototype users guide: Captains S. Griffith, L. Medal, and C. Shipman, and SMSGT Gentry of the Air Force Maintenance and Supply Management Engineering Team at Wright-Patterson AFB, Ohio; and Mr. L. Jordan and Capt. W. Radcliffe of the Air Force ASD/ENEC Office at Wright-Patterson AFB, Ohio.

INTRODUCTION

Background

Increasing costs of new Air Force weapons systems and limited budgets represent major constraints for Air Force planners and designers. Research programs initiated in response to these constraints have resulted in new or improved materials, more efficient designs, and new manufacturing techniques and processes.

Research has also been initiated to investigate the impact of new systems on human resource requirements. The assumptions underlying this area of research are that while advanced materials and designs help reduce costs, new systems must also efficiently utilize personnel and provide for effective levels of personnel performance. Further, if a new system appears to have an adverse impact on human resource requirements, the earlier in the design process this impact can be identified, the easier it is to effect changes in the system design to overcome this adverse effect.

The problem of gathering human resource data in the early stages of system design is gaining increasing attention. Two recent studies (Sauer & Askren, 1978a; Whalen & Askren, 1974) have investigated the feasibility of obtaining maintenance personnel requirements and performance data during the conceptual phase of system design using subjective estimate techniques. These data were obtained through estimates made by experienced maintenance technicians. This approach, called the expert estimate method, produced satisfactory estimates of maintenance person-hours, crew size, skill level, career field, and task difficulty. On the basis of these results, Sauer & Askren (1978b) also prepared a prototype users guide describing the steps and procedures for collecting expert estimates.

While the results of these studies were encouraging, it should be noted that they were limited to a small number of aircraft avionics subsystems and used only aircraft avionics technicians as estimators. Additional research is necessary to provide a better understanding of the general utility of the expert estimate method of generating personnel requirements and performance data. The method, as described in the prototype users guide, should be extended to a different technology area and technician specialty field. In this way, it is possible to assess how well the procedure transfers to other systems and to evaluate the procedures contained in the prototype users guide.

Objectives

The objectives of the study were to exercise an expert estimate method of generating maintenance and manpower data for new systems, to

determine the accuracy of these estimated data, to collect cost data for implementing the method, to evaluate a prototype guide describing the method, and to prepare a revised users guide for the expert estimate method.

RESEARCH APPROACH

The research approach was similar to the Sauer and Askren (1978a; 1978b) study and followed the recommendations in the prototype guide produced from that study. An engineering description of an operational ground radar system was prepared to include only information that would have been available during the early design phase of the system. A supplement to the engineering description (using early design phase information only) was also prepared to determine the effects of additional information on the estimates. Using only the engineering description and its supplement, technicians with various types of ground radar maintenance experience (one career field, three Air Force Specialty Codes [AFSCs]) estimated manpower, maintenance, and training requirements for that system. The technicians' estimates were compared with manpower, maintenance and training data available on the operational system to determine the validity of those estimates.

Other portions of the research effort involved the collection of critiques of the expert estimate prototype users guide, and collection of data which could be used to estimate the cost of using the expert estimate method.

Selection of Operational System

The AN/TPS-43(E), a mobile, three-dimensional ground-based radar system was chosen as the test system. The system had both early engineering data and operational data available. It had been deployed with Tactical Air Command units for approximately 18 months when the data collection effort took place and the system represented state-of-the-art technology. It was expected that an engineering description of a new state-of-the-art system would appear as a plausible advanced system to the estimators in this study.

Development of Engineering Description Package

The engineering description package was developed following the recommendations and examples provided in the prototype users guide (Sauer & Askren, 1978b). Engineering information was provided by Tactical Air Command Headquarters. Electronics engineers from Systems Research Laboratories, Inc. (SRL), edited and combined this information to form the basic engineering description package and the supplement to the basic package. The engineering description contained an acronym glossary, a general system description, component descriptions, built-in test equipment descriptions, illustrations, and a block diagram of the system. The supplement contained additional engineering data on system components.

Estimating Manpower, Maintenance, and Training Data Items

The data items that the technicians were asked to estimate are presented in Table 1. The sources of the operational data used to validate the estimates are also presented in Table 1. The data items include items satisfactorily estimated in previous studies: person-hours, crew size, skill level, and career field/AFSC. Other data

TABLE 1. TYPES OF DATA FOR WHICH ESTIMATES WERE COLLECTED AND SOURCES OF CORRESPONDING OPERATIONAL DATA

Types of Data	Sources of Operational Data
Person-hours	AFM 66-1 Data
Crew Size	AN/TPS-43(E) System Experts
Skill Level	AN/TPS-43(E) System Experts
Troubleshooting Difficulty	AN/TPS-43(E) System Experts
Percentage of Maintenance Task Occurrences	AFM 66-1 Data
Career Field/AFSC	AN/TPS-43(E) System Experts
Training Times	AN/TPS-43(E) System Experts
Support Equipment Requirements	AN/TPS-43(E) Technical Order

skill level, and career field/AFSC. Other data items which appeared to have potential applications in early system design and planning studies were also included: troubleshooting difficulty, percent of maintenance task occurrences, training times, and support equipment requirements. In all cases, an item was included only if a satisfactory source of operational data could be obtained. Details of each data item and its corresponding operational data set are presented in the following paragraphs.

Maintenance Scenarios. Maintenance scenarios were developed to help technicians make estimates of all maintenance and manpower items except career field/AFSC, training time requirements, and support equipment requirements. The maintenance scenario establishes a context or frame of reference for making these estimates. It includes four types of information: (a) the general type of maintenance

(on- or off-equipment), (b) the name of the component and its work unit code (WUC), (c) the type of malfunction, and (d) the specific maintenance action performed to correct the malfunction.

The estimates that technicians made for maintenance and manpower data items were grouped by two general types of maintenance: on-equipment maintenance and off-equipment maintenance. Six components and their associated WUCs were selected for the on-equipment maintenance estimates. They were:

1. RF (radar frequency) receivers
   AAAAD

2. Transmitter
   ABA00

3. SF_6 (sulfur hexafluoride) tank
   ABAH0

4. IF (intermediate frequency) receiver
   ABF00

5. IF height receiver
   ABFD0

6. IF Search/MTI (moving target indicator)
   ABFF0

Three malfunctions and their associated maintenance actions were identified for each of the six components. A total of 18 maintenance scenarios was constructed for the estimates of on-equipment maintenance and manpower data. The set of 18 scenarios is contained in Table 2.

It will be noted that not all scenarios contained specific malfunctions or actions taken. The first scenario for each component (No. 1, 4, 7, 10, 13, 16) did not specify a particular malfunction or maintenance action. The intent here was to present to the technicians a general maintenance scenario for each component. Estimates of task times using these scenarios would be similar to Mean Time to Repair (MTTR) values for the components. The estimates of crew size and skill levels and the derived estimates of person-hours for these scenarios represented general work estimates of these data. Maintenance scenarios for troubleshooting tasks did not specify a particular malfunction.

Maintenance scenarios for off-equipment tasks are presented in Table 3. Each numbered column is a separate scenario. The first scenario for each component (No. 1, 3, 5, 7) was intended to present to the technicians a general off-equipment maintenance scenario. Task time estimates for these scenarios would be similar to the MTTR values.

TABLE 2. ON-EQUIPMENT MAINTENANCE SCENARIOS 1 TO 18

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
Component and Work Unit Code	RF Receiver AAAAD	RF Receiver AAAAD	RF Receiver AAAAD	Transmitter ABAOO	Transmitter ABAOO	Transmitter ABAOO
How Malfunction	Not Specified	Not Specified	No Output	Not Specified	Not Specified	No Output
Action Taken	General Maintenance	Troubleshoot	Remove & Replace	General Maintenance	Troubleshoot	Minor Repair

	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12
Component and Work Unit Code	SF_6 Tank ABAHO	SF_6 Tank ABAHO	SF_6 Tank ABAHO	IF Receiver ABFOO	IF Receiver ABFOO	IF Receiver ABFOO
How Malfunction	Not Specified	Not Specified	Pressure Incorrect	Not Specified	Not Specified	Adjusted Improperly
Action Taken	General Maintenance	Troubleshoot	Minor Repair	General Maintenance	Troubleshoot	Adjust

	Scenario 13	Scenario 14	Scenario 15	Scenario 16	Scenario 17	Scenario 18
Component	IF Height Receiver ABFDO	IF Height Receiver ABFDO	IF Height Receiver ABFDO	IF Search/MTI Receiver ABFFO	IF Search/MTI Receiver ABFFO	IF Search/MTI Receiver ABFFO
How Malfunction	Not Specified	Not Specified	No Output	Not Specified	Not Specified	Adjusted Improperly
Action Taken	General Maintenance	Troubleshoot	Minor Repair	General Maintenance	Troubleshoot	Adjust

TABLE 3. OFF-EQUIPMENT MAINTENANCE SCENARIOS 1 TO 18

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Component and Work Unit Code	RF Receiver AAAAD	RF Receiver AAAAD	Power Supply Focus Coil ABAGO	Power Supply Focus Coil AGAGO
How Malfunction	Not Specified	Not Specified	Not Specified	No Output
Action Taken	General Maintenance	Any NRTS Action	General Maintenance	Shop Repair

	Scenario 5	Scenario 6	Scenario 7	Scenario 8
Component and Work Unit Code	IF Height Receiver ABFDO	IF Height Receiver ABFDO	IF Search/ MTI Receiver ABFFO	IF Search/ MTI Receiver ABFfO
How Malfunction	Not Specified	No Output	Not Specified	Not Specified
Action Taken	General Maintenance	Shop Repair	General Maintenance	Any NRTS[a] Action

[a]Not Repairable This Station

Task time, crew size, and skill level estimates and derived person-hour estimates were made for each maintenance scenario (on-equipment = 18, off-equipment = 8). In addition, troubleshooting difficulty estimates were made for each on-equipment scenario which specified a trouble-shooting task (n = 6), and percent of maintenance task occurrences estimates were made for each of the six components identified in the on-equipment maintenance scenarios.

person-hours, however; they estimated task time and crew size. A person-hour estimate was derived by multiplying the technician's task time estimate by the crew size estimate. There were two reasons for using this approach. First, the AFM 66-1 (Maintenance Management Policy) operational data which were available were in the form of person-hours. The derived person-hour estimates, therefore, could be directly compared to the operational data. Second, technicians do not record their maintenance data in terms of person-hours. When they complete the maintenance data form, AFTO Form 349 (Maintenance Data Collection Record), they enter task time and crew size, but not person-hours. Technicians were therefore asked to estimate the same types of data they were familiar with in their daily recordkeeping activities. The person-hour operational data for the on- and off-equipment maintenance tasks were taken from AFM 66-1 maintenance data for the AN/TPS-43(E) radar system. On-equipment person-hour data were for the 12-month period beginning 01 October 1977 and ending 30 September 1978. The off-equipment person-hour data were for the 12-month period beginning 01 September 1977 and ending 31 August 1978.

Crew Size Estimates and Operational Data. Crew size was defined as the number of technicians required to perform the specified maintenance tasks. Technicians estimated the percentage of time that a one-, two-, three-, and four-member crew would be required to perform the specified maintenance task. The sum of the percentages for a given task equals 100. Crew size estimates were made for the 18 on-equipment and 8 off-equipment maintenance tasks. Operational data for crew size were obtained from four system experts who had extensive maintenance experience on the AN/TPS-43(E) (Table 4). The system experts provided the estimate of the percentage of time a particular crew size would be required for a given maintenance task.

TABLE 4. SPECIALTIES, SKILL LEVELS, AND EXPERIENCE OF THE FOUR AN/TSP-43(E) SYSTEM PERSONNEL USED AS EXPERTS IN GENERATING OPERATIONAL DATA

AFSC	N	Skill Levels		Months of Systems Experience	
		7	9	Mean	Range
303X2	4	3	1	19.5	18 - 24

Skill Level Estimates and Operational Data. Skill level was defined in terms of the Air Force skill level classifications of 3, 5, 7, and 9. Technicians estimated the skill level requirements in

conjunction with their crew size estimates. No skill levels were estimated for crew sizes assigned a percentage score of zero. Operational data for skill levels were provided by the system experts described earlier (Table 4).

Career Field/AFSC Estimates and Operational Data. Career field was defined as the first three digits of the five-digit AFSC assigned to Air Force enlisted personnel. Technicians first were asked to estimate career field requirements for the new system. Technicians then were asked to estimate either the specific five-digit AFSC which would be assigned to maintain the system or the actions which would be necessary to obtain the proper maintenance personnel for the system. System experts (Table 4) provided the operational career field/AFSC requirements for the system.

Percentage of Maintenance Task Occurrences Estimates and Operational Data. Percentage of maintenance task occurrences was defined as the percentage of on-equipment maintenance tasks for a particular component which could be placed into one of five maintenance categories. The five categories were: (a) Minor Repair, (b) Install/Remove/Remove and Replace, (c) Adjust, (d) Troubleshoot, and (e) Other. Four categories represented the four types of specific maintenance activities most frequently performed on the ground-based radar system, and a fifth category represented the remaining maintenance activities. Given all the maintenance actions which could be performed on a component (100 percent of the maintenance tasks), the technician estimated the percentage of these tasks that would be categorized into each of the five categories. These types of estimates provided an indication of how the maintenance actions would be distributed for a given component. Operational data were the percentage of on-equipment maintenance actions actually recorded in the five categories for the six system components. These data were extracted from AFM 66-1 maintenance data.

Troubleshooting Difficulty Estimates and Operational Data. Troubleshooting difficulty was defined as the degree of difficulty involved in performing troubleshooting tasks for the six system components for which on-equipment maintenance tasks were specified. The estimates were made on a 100-mm scale ranging from 0 (Very Easy) to 100 (Very Difficult). The operational data were similar ratings made by the system experts (Table 4), based on their maintenance experience with the AN/TPS-43(E) radar.

Training Time Estimates and Operational Data. In this study maintenance technicians estimated the weeks of technical training, field training detachment training, and on-the-job training necessary to bring an experienced radar technician and a new radar technician (no previous radar experience) up to 5-level maintenance performance on the proposed system. Previous attempts to collect training data estimates involved very detailed questions on content and times (Sauer

& Askren, 1978a) and resulted in inadequate training data estimates. A simpler, more direct approach was tried, commensurate with the amount of engineering information available in the early design stage of system development. The operational data, actual training times for the AN/TPS-43(E) radar, were provided by the system experts (Table 4).

Support Equipment Estimates and Operational Data. Support equipment requirements were defined as the types of tools and test equipment necessary to support the maintenance program for the radar system. Technicians used an open-end response format to record their estimates of the types of equipment necessary. Operational data were the types of tools and test equipment actually required to support maintenance on the system. This information was extracted from the AN/TPS-43(E) technical manuals.

Collection of Additional Data. The technicians provided the following additional information: work experience, ratings of their confidence in their estimates, the percent of each estimate based on their past maintenance experience and on the engineering data provided, and the effect the additional engineering data had on their estimates.

Estimator Personnel

Personnel participating as expert estimators were radar maintenance technicians from three AFSC groups: 303X1, air traffic control radar technicians; 303X2, aircraft control and warning radar technicians; and 303X3, automatic tracking radar technicians. These groups represented all AFSC groups within the 303XX career field. This is the career field one would have selected in an actual application of the method based on recommendations in the prototype guide (Sauer & Askren, 1978b). The number of technicians participating from each group, and the years of maintenance experience and skill levels possessed by the technicians are presented in Table 5. None of these technicians had work experience on the AN/TPS-43(E).

TABLE 5. HUMAN RESOURCES DATA ESTIMATOR CHARACTERISTICS: AFSC, SKILL LEVELS, YEARS OF AFSC EXPERIENCE [NO EXPERIENCE ON AN/TPS-43(E)]

AFSC Group	Skill Level					Years of AFSC Experience	
	N	3	5	7	9	Mean	Range
303X1	16	1	4	10	1	8.6	<1.0-22.3
303X2	25	1	15	9	--	7.6	1.4-19.8
303X3	29	7	12	10	--	4.7	<1.0-16.0

Data Collection

Prior to the actual data collection effort, SRL employees with previous Air Force radar maintenance experience reviewed the engineering description package, the questionnaire, and the proposed procedures to be used in the data collection effort to identify any unforeseen data collection problems.

Table 6 contains a listing of the units visited, their parent commands, and the bases where the units were located. The data collection occurred in group settings of from 4 to 15 technicians. Each technician was given a copy of the basic engineering description package and the maintenance manpower questionnaire. The questionnaire administrator briefed the technicians on the purpose of the research project prior to giving the verbal instructions for the questionnaire. Technicians were advised to read through the entire basic engineering description before attempting to make their estimates. The technicians were encouraged to refer to the engineering description as often as necessary during the session.

Upon completion of the questionnaire, technicians were given a copy of the supplement to the basic engineering description package. They were instructed to read the additional engineering information and go back through and reconsider their initial estimates. If, based upon the additional engineering information, they wished to change an estimate, they were instructed to circle the initial estimate and enter the new estimate adjacent to the initial estimate. At this time, the technicians were also given the last page of the questionnaire to collect their confidence ratings of their estimates, the information sources used for their estimates, and the effect the supplemental engineering data had on their estimates.

TABLE 6. BASES, COMMANDS, UNITS, AND TECHNICIAN ESTIMATORS PARTICIPATING IN THE DATA COLLECTION EFFORT

Base	Command	Unit	n	AFSC
Port Austin AFS	ADC	754th Radar Sqdn.	25	303X2
Avon Park Air Force Range	TAC	56th Combat Support Squadron	25	303X3
Eglin AFB	TAC	75th Tactical Control Flight	4	303X3
	AFCS	1972 Comm Sqdn.	4	303X1
Patrick AFB	AFCS	2179 Comm. and Installation Group	6	303X1
Wright-Patterson AFB	AFCS	2046 Comm. and Installation Group	6	303X1

Prototype Users Guide Evaluation

A total of seven manpower experts from the Air Force Maintenance and Supply Management Engineering Team and the Crew Equipment and Human Factors Division of the ASD Directorate of Equipment Engineering at Wright-Patterson AFB, reviewed and critiqued the contents and methodology presented in the prototype users guide. Seven questions were prepared and distributed with each copy of the guide. The questions addressed the clarity of the writing and explanations, the adequacy of the information and examples provided, and the feasibility of suggested applications for the method. The last question was open-ended and solicited any additional comments and criticism.

Cost Evaluation

To evaluate the potential cost of collecting expert estimates, person-hours were tracked for each phase of the data collection effort. Those person-hours which were required only for execution of the research approach, such as selection of a test system and the collection of operational data, were excluded from the cost analysis.

RESULTS

Accuracy Measures

To evaluate the accuracy of the various maintenance and manpower data estimates, several kinds of accuracy measures were used. For crew size, troubleshooting difficulty, and training time estimates, and derived person-hour estimates, the accuracy index or score was calculated by dividing the estimated value by the actual or criterion value (Estimate ÷ Actual = Accuracy Score). An accuracy score of 1.00 indicated that the estimate was the same as the actual value. An accuracy score less than 1.00 indicated that the estimated value was less than the actual value (underestimate), while an accuracy value greater than 1.00 indicated an estimated value greater than the actual value (overestimate). For estimates of the most likely crew size, skill levels, career field/AFSC, and support equipment requirements, the percentage of estimates that agreed with the actual or criterion value was the indicator of accuracy.

For estimates of percentage of maintenance task occurrences, the degree of agreement between the list of estimated percentages and the list of actual percentages was examined. A chi-square analysis was used to compare the estimated percentages with the actual percentages. No differences between the estimated percentages (observed) and the criteria percentages (expected) would indicate that technicians' estimates of percent of maintenance task occurrences were similar to the actual percent of occurrences.

Person-Hour Values

Person-hour values were obtained for on- and off-equipment maintenance tasks. The values were derived by multiplying each technician's normal task time estimate by the crew size that had been estimated as the most likely to perform the particular task. The mean person-hour value for a given task was calculated for each AFSC group. This mean person-hour value was compared to the mean person-hours reported for that task in the AFM 66-1 maintenance data base for the AN/TPS-43(E) radar system.

Person-hour values and accuracy scores were calculated for 18 on-equipment maintenance tasks: three maintenance tasks for each of the six components/WUCs (see Table 2). For the general maintenance tasks (the first maintenance scenario for each component/WUC), the technicians were instructed to estimate normal, minimum, and maximum task times for general on-equipment maintenance tasks (except troubleshooting tasks) for the component. These estimates would be similar to those for MTTR. For the remaining maintenance scenarios, the technicians estimated task times for troubleshooting tasks and other specific maintenance tasks.

The estimating accuracy of the three AFSC groups was compared for all on-equipment maintenance task types. A Kruskal-Wallis one-way analysis of variance procedure indicated no significant differences in terms of accuracy of the estimates among the three AFSC groups (Kruskal-Wallis $H = 1.42$, $p < .50$). Estimating accuracy, however, did vary by type of maintenance task (Kruskal-Wallis $H = 5.96$, $p < .02$). The technicians produced the most accurate estimates for the specific maintenance tasks. General maintenance tasks were next best in terms of accuracy, and troubleshooting tasks had the worst accuracy record. A summary of the mean person-hour values, the AFM 66-1 data, and the accuracy scores for the three types of on-equipment tasks and the three AFSC groups is given in Table 7.

Off-equipment maintenance person-hours were calculated in the same manner as the on-equipment maintenance person-hours. Technicians estimated task times for four work unit codes and two types of off-equipment tasks: general tasks, which were defined as all possible shop actions for a given work unit code; and specific tasks, which were defined in terms of a specific "how malfunction" code and "action taken" code or as any "NRTS" (Not Repairable This Station) action.

A Kruskal-Wallis one-way analysis of variance indicated there were no significant differences among the three AFSC groups with regard to the accuracy of off-equipment maintenance person-hour values ($H = 3.71$, $p = .20$). Also presented in Table 7 is a summary of mean person-hour values, AFM 66-1 mean person-hours, and accuracy scores for the three AFSC groups and two types of off-equipment maintenance tasks. In contrast to the on-equipment person-hour values, there were no significant differences in the accuracy of off-equipment person-hour values by the types of maintenance tasks (Mann-Whitney $U = 3$, $p = .35$). Overall, technicians tended to underestimate on-equipment person-hours while off-equipment person-hour values for the groups were both over and under actual person-hours. The accuracy scores for estimates of general shop actions were very close to 1.00 with perhaps a slight tendency to underestimate person-hours. For specific shop actions, the technician generally overestimated person-hours. The overall accuracy for all groups and both types of maintenance was .80. For comparison purposes, the accuracy values reported previously were .66 (Sauer & Askren, 1978a) and .70 (Whalen & Askren, 1974).

Crew Size Estimates

Technicians estimated crew size requirements in terms of the percentage of time a one-, two-, three-, and four-member crew was required to perform the specified maintenance task. For example, a technician who estimated a value of 10 for a one-member crew and a

TABLE 7. AFM 66-1 PERSON-HOUR DATA, MEAN PERSON-HOUR VALUES AND ACCURACY SCORES FOR ON- AND OFF-EQUIPMENT MAINTENANCE TASKS FOR THREE AFSC GROUPS

Types of Maintenance Tasks	AFM 66-1 Mean Person-Hours	Person-hour Values (V) and Accuracy Scores[a] (A) for AFSC Groups						
		303X1		303X2		303X3		Task Mean Accuracies
		V	A	V	A	V	A	
On-Equipment								
General	4.30	1.86	.43	2.41	.56	2.85	.66	.55
Troubleshoot	7.63	2.61	.34	1.84	.24	2.97	.39	.32
Specific	2.24	1.20	.54	1.61	.72	2.32	1.03	.76
Off-Equipment								
General	2.82	2.30	.81	2.22	.79	3.86	1.37	.99
Specific	2.64	2.63	.99	2.92	1.10	5.47	2.07	1.39
Group Mean Accuracy			.62		.68		1.10	
Overall Mean Accuracy								.80

[a] $\text{Accuracy Score} = \frac{\text{Mean Person-hour Values for Task Type}}{\text{Mean AFM 66-1 Person-hours for Task Type}}$

value of 90 for a two-member crew was stating that, 90 percent of the time, two persons would be required to perform the task, and 10 percent of the time, one member would be required to perform the task. In this example, three- and four-member crews were considered unnecessary for performance of the task and were therefore assigned values of 0.

The first analysis conducted on the crew size estimates was to determine how well the AFSC groups estimated the crew size most likely to perform the specified tasks. The accuracy measure used here was the percentage of times the technicians correctly estimated the most likely crew size for both on- and off-equipment maintenance tasks. These percentages (Table 8) ranged from 41.6 percent for the 303X3 technicians, 45 percent for the 303X1 technicians, to 70 percent for the 303X2 technicians.

TABLE 8. PERCENT OF MAINTENANCE TASKS WHERE ESTIMATORS CORRECTLY INDICATED THE CREW SIZE MOST LIKELY TO PERFORM THE TASK

	AFSC Groups		
Maintenance Tasks	303X1	303X2	303X3
On-Equipment			
General Tasks	33%	100%	100%
Troubleshoot Tasks	50%	50%	50%
Specific Tasks	67%	50%	33%
Off-Equipment			
General Tasks	25%	75%	25%
Specific Tasks	50%	75%	0%
Overall	45%	70%	41.6%

Although no statistically significant differences were found among the groups (Kruskal-Wallis $H = 3.67$, $p < .20$), the 303X2 technicians appeared to make more accurate estimates of crew size than did the other two groups.

An analysis of the incorrect estimates indicated that the magnitude of the errors never exceeded plus or minus one crew

member. The tendency was for technicians to estimate larger rather than smaller crew sizes. They overestimated crew size by one in 28 of the 36 tasks (78 percent) for which incorrect crew size estimates were made. For the remaining eight tasks (22 percent) they underestimated crew size by one.

The mean accuracy scores by AFSC group for estimating the percentage of time crew sizes of one and two are required are presented in Table 9. The accuracy score was calculated by dividing the estimated percent of time a one- and two-member crew would be required by the actual percent of time a one- and two-member crew would be required.

TABLE 9. MEAN ACCURACY SCORES FOR ONE- AND TWO-MEMBER CREW SIZE ESTIMATES

Maintenance Tasks	Crew Size	Mean Accuracy Scores[a] by AFSC Groups 303X1	303X2	303X3
On-Equipment				
General Tasks	1	1.78	1.28	.05
	2	.71	.94	1.02
Troubleshooting Tasks	1	1.91	1.80	.06
	2	.91	1.05	1.11
Specific Tasks	1	1.93	1.29	.03
	2	1.55	2.17	3.22
Off-Equipment				
General Tasks	1	1.85	1.41	.19
	2	.99	1.07	1.35
Specific Tasks	1	.60	.50	.10
	2	5.01	5.62	7.48
Overall	1	1.61	1.26	.09
Overall	2	1.83	2.17	2.84

[a]Accuracy Score = $\dfrac{\text{Estimated Percent of Times a Crew Size is Required}}{\text{Actual Percent of Times a Crew Size is Required}}$

The accuracy with which the AFSC groups estimated the percent of time a one-member crew would be required to perform a given task

differed significantly among the groups (Kruskal-Wallis H = 8.42, $p < .02$). The 303X1 and 303X2 technicians had overall accuracy scores of 1.61 and 1.26, respectively, indicating they overestimated the percentage of time a one-member crew would be required. The overall accuracy scores for the 303X2 group, however, demonstrated an acceptable degree of estimating accuracy. The 303X3 technicians had an overall accuracy score of .09, indicating they greatly underestimated the percentage of times a one-member crew would be required. No such accuracy differences were found among the AFSC groups for estimates of two-member crew requirements (Kruskal-Wallis H = .38, $p < .90$). The technicians generally overestimated the percent of times a two-member crew would be required for a given task.

Crew size estimates for one- and two-member crews were also compared over the various types of maintenance tasks. No differences were found in terms of accuracy of crew size estimates over the three types of on-equipment tasks: general, troubleshooting, and specific (Kruskal-Wallis H = 3.26, $p < .20$). However, for the off-equipment tasks, crew size estimates were more accurate for the general tasks than for the specific tasks (Mann-Whitney U = 3, $p = .008$). No analyses were conducted on the three- and four-member crew size estimates because of the relatively few estimates made for these crew sizes.

It appears that for both types of crew size estimates, the most likely crew size and the percentage of times crews of one and two members are required, the 303X2 technicians performed somewhat better than either of the other AFSC groups. Where errors occurred, the tendency was for technicians to overestimate. For most likely crew size estimates, the majority of the errors were overestimates of crew sizes by one crew member. Technicians also overestimated the percentage of times one- and two-member crews were required. The magnitude of these overestimates appeared to be slightly less for a one-member crew than for a two-member crew.

Skill Level Estimates

Skill level estimates (3, 5, 7, or 9) were made to correspond to each crew size estimate. The percentage of correct skill level estimates, when compared to the operational data, was the measure used in these analyses. For crew sizes greater than one, all skill levels must agree with the criterion skill levels for the particular maintenance scenario to be considered a correct response. No partial credit was allowed if only one of two or more skill level estimates was correct. For example, the operational data may indicate that for a crew of two, a 5-level and a 7-level technician are required. The only correct estimate in this case is a 5- and 7-level technician team. A 5- and 5-level team, a 5- and 3-level team, or any other combination other than the 5- and 7-level team was considered incorrect in these analyses. This measure of correct

skill level estimates could be considered a conservative measure for crew sizes greater than one. The percentage of correct skill level estimates for the AFSC groups over the various types of maintenance tasks is displayed in Table 10. Analyses for three- and four-member crews were not included due to the limited data for these crew sizes.

TABLE 10. PERCENT OF CORRECT SKILL LEVEL ESTIMATES FOR ONE- AND TWO-MEMBER CREWS

		Percent of Correct Skill Level Estimates for AFSC Groups		
Maintenance Tasks	Crew Size	303X1	303X2	303X3
On-Equipment				
General Tasks	1	65.5	57.2	48.8
	2	33.3	17.0	3.0
Troubleshooting Tasks	1	66.8	57.5	33.3
	2	35.8	16.3	5.2
Specific Tasks	1	83.3	71.7	39.0
	2	61.5	55.5	58.8
Off-Equipment				
General Tasks	1	76.7	65.7	35.7
	2	53.7	50.0	35.5
Specific Tasks	1	98.0	80.0	53.3
	2	73.3	69.0	62.3
Mean Percentage of Correct Estimates	1	78.1	66.4	42.0
	2	51.5	41.6	33.0

Considering overall performance for estimating skill level, significant differences were found among the three AFSC groups (Kruskal-Wallis $H = 7.76$, $p < .05$). The 303X1 group had the highest percentage of correct estimates and the 303X3 group had the lowest percentage of correct estimates. This finding was heavily influenced by the groups' performance differences on skill level estimates for

one-member crews (Kruskal-Wallis H = 10.22, $p < .0097$). There were no significant differences among the groups for skill level estimates for two-member crews (Kruskal-Wallis H = 1.14, $p < .70$).

In comparing skill level estimates (crew sizes of one and two) for the different on-equipment maintenance tasks, the data suggested that the skill level estimates were more accurate for specific on-equipment tasks than for the general and troubleshooting tasks (Kruskal-Wallis H = 4.64, $p < .10$). For off-equipment tasks, however, skill level estimates were clearly superior for the specific tasks (Mann-Whitney U = 7, $p = .047$).

As indicated above, the percentage of correct skill level estimates is a conservative measure for crew sizes greater than one. For 77 out of 78 skill level estimates for crew sizes of two, at least one of the skill levels estimated for the two-member crew was correct. To determine the nature of the errors in the skill level estimates, an analysis of the incorrect skill level estimates for crews of one and two was conducted. It was found that technicians generally underestimated skill level requirements. Overall, 28.4 percent of the skill level estimates for crews of one and two indicated that a numerically lower skill level or combination of skill levels was estimated for the task. Overestimates of skill level requirements occurred for 19.6 percent of the estimates. Overall for crew sizes of one and two, 52.0 percent of the skill level estimates were correct.

Troubleshooting Difficulty Estimates

The troubleshooting difficulty estimates were made on a 100-mm scale with verbal anchors of Very Easy (0 mm), Average Difficulty (50 mm), and Very Difficult (100 mm). Technicians estimated the degree of troubleshooting difficulty for six system components. Troubleshooting tasks represented on-equipment maintenance. The AN/TPS-43(E) system experts used the same scale to generate the criteria troubleshooting difficulty ratings. The criteria troubleshooting difficulty ratings, group estimates of troubleshooting difficulty, and the accuracy scores for the six work unit codes representing the six system components are depicted in Table 11. No differences were found among the AFSC groups in terms of accuracy of troubleshooting difficulty ratings. The accuracy score for the groups was 1.28, indicating a tendency to overestimate the difficulty of these troubleshooting tasks. An analysis of the accuracy scores by system component, however, indicated significant differences in accuracy occurred depending on the component (Kruskal-Wallis H = 15.15, $p < .02$). An inspection of the accuracy scores indicates that this difference may be due to the fact that technicians greatly overestimated the troubleshooting difficulty for the RF receivers (Work Unit Code AAAAD). Considering the accuracy scores

TABLE 11. TROUBLESHOOTING DIFFICULTY RATINGS AND ACCURACY SCORES FOR SIX ON-EQUIPMENT WORK UNIT CODES

		Troubleshooting Difficulty Ratings (R) and Accuracy Scores[a] (A) for AFSC Groups					
		303X1		303X2		303X3	
WUC	Criterion Rating	R	A	R	A	R	A
AAAAD	15	46	3.07	50	3.33	51	3.40
ABAOO	63	53	.84	49	.78	55	.87
ABAHO	93	57	.61	42	.45	52	.56
ABFOO	53	52	.98	48	.91	59	1.11
ABFDO	53	59	1.11	50	.94	56	1.06
ABFFO	53	51	.96	50	.94	55	1.04

[a]Accuracy Score = $\frac{\text{Estimated Difficulty Rating}}{\text{Criterion Difficulty Rating}}$

for all work unit codes except AAAAD, the overall mean accuracy score drops to .88, indicating that technicians tended to underestimate the troubleshooting difficulty for these components. An inspection of Table 11 suggests that this accuracy score (excluding the AAAAD data) may be a better indicator of the technicians' ability to estimate troubleshooting difficulty.

Percent of Maintenance Task Occurrence Estimates

Technicians were asked to estimate the percentage of time certain types of maintenance tasks would be performed on a given equipment component over a specific period of time. Estimates were made in terms of the percentage of maintenance tasks performed on a component which could be categorized into five task types: minor repair, install/remove/remove and replace, adjust, troubleshoot, and other maintenance. The estimates for the five task categories for any equipment component total 100 percent. These estimates were made for six system components (six work unit codes). The estimates for a given component were compared to the frequency of occurrence of the tasks as determined from AFM 66-1 maintenance data. A chi-square analysis was performed to compare the estimate percentages

with the AFM 66-1 maintenance percentages (frequency of occurrence per 100 maintenance actions). If no statistical differences were found between the expected frequencies (AFM 66-1 data) and the observed frequencies (estimates), one could conclude that the technicians were doing a fairly good job of estimating the percentage of maintenance task occurrences. However, the values of chi-square for the AFSC groups and six system components as presented in Table 12 ranged from $\chi^2 = 8.28$, $p < .10$, to $\chi^2 = 399.94$, $p < .001$. These values indicate that the technicians' estimates of the percentages of maintenance task occurrences differ significantly from the percentages reported in the AFM 66-1 data. Technicians did not demonstrate that they could accurately estimate the distribution of maintenance tasks for a given component.

Career Field/AFSC Estimates

Technicians first estimated the career field and then the specific AFSC which would have responsibility for the maintenance of the radar system. Presented in Table 13 is the percentage of correct estimates for both career field and AFSC for the three estimator groups. The results indicate that technicians can estimate career field requirements very well. Although the AFSC estimates exhibit more variability than the career field estimates, the majority of each estimator group correctly identified the required AFSC for the radar system.

TABLE 12. CHI-SQUARE VALUES RESULTING FROM ANALYSES OF ESTIMATED AND ACTUAL PERCENT OF MAINTENANCE TASK OCCURRENCES FOR SIX SYSTEM COMPONENTS BY AFSC GROUPS

	χ^2 Values by Estimator Groups		
Component	303X1	303X2	303X3
RF Receiver AAAAD	399.94	281.73	287.10
Transmitter ABAOO	47.46	93.93	106.76
SF_6 Tank ABAHO	18.68	13.80	16.82
IF Receiver Assy. ABFOO	154.69	195.72	195.48
IF Height Receiver ABFDO	24.42	11.44	12.66
IF Search/MTI Receiver ABFFO	12.95	8.28	20.97

Note: Critical Values of χ^2 with 4 df: χ^2 7.78, $p < .10$
χ^2 9.49, $p < .05$
χ^2 13.78, $p < .01$

TABLE 13. CAREER FIELD AND AFSC ESTIMATES BY ESTIMATOR GROUPS

	Estimator Groups		
Career Field Estimates	303X1	303X2	303X3
303XX[a]	88%	96%	96%
Other	12%	4%	4%
	100%	100%	100%
AFSC Estimates			
303X1	31%		8%
303X2[b]	38%	92%	64%
303X3			24%
Other	31%	8%	4%
	100%	100%	100%

[a]Actual Career Field.

[b]Actual AFSC.

Time To Train Estimates

Technicians were asked to estimate the number of weeks of technical training, field training detachment (FTD) training, and on-the-job training which would be necessary for a technician to achieve 5-level maintenance proficiency on the proposed system. Two types of technicians were specified: a technician with radar maintenance experience transitioning to the new system and a prospective radar technician recently graduated from basic training. The estimated training times (in weeks) were compared to the training times experienced or observed by the AN/TPS-43(E) experts. The criteria training times, estimated training times, and accuracy scores for the three AFSC groups are given in Table 14. No differences were found among the AFSC groups with respect to the accuracy of the training time estimates (Kruskal-Wallis $H = .67$, $p < .80$). However, significant accuracy differences were found depending on the type of

TABLE 14. TRAINING TIME ESTIMATES AND ACCURACY SCORES FOR AFSC GROUPS

Types of Training by Personnel Experience Level	Criteria[a]	Training Time Estimates[a] (E) and Accuracy Scores[b] (A) for AFSC Groups						Training Type Mean Accuracy
		303X1		303X2		303X3		
		E	A	E	A	E	A	
Experienced Radar Technician								
Technical Training	16	1.9	.62	9.8	.61	10.4	.65	.63
Field Training Detachment	6	8.0	1.33	9.4	1.57	7.9	1.32	1.41
On-the-Job	21	19.3	.92	22.4	1.07	14.0	.67	.89
Basic Training Graduate								
Technical Training	26	29.9	1.15	27.9	1.07	30.6	1.18	1.13
Field Training Detachment	7	20.0	2.86	19.7	2.81	17.8	2.54	2.74
On-the-Job	40	36.6	.92	39.3	.98	24.0	.60	.83
Group Mean Accuracy			1.30		1.35		1.16	
Overall Mean Accuracy								1.27

[a]Criteria and estimates are expressed in terms of weeks of training.

[b]Accuracy Score = $\frac{\text{Estimated Weeks of Training}}{\text{Criteria Weeks of Training}}$.

training for which estimates were made (Kruskal-Wallis $H = 6.86$, $p < .05$). The field training detachment estimates appeared to be responsible for this difference. Technicians considerably overestimated the training time required for this FTD training. The technicians' estimates of training times for the other types of training came much closer to the actual training times. Although technicians generally overestimated (overall accuracy value = 1.27) training time, the estimates would appear to be of value in the early design stages.

Support Equipment Requirements Estimates

Technicians were asked to estimate the support equipment requirements for the new system, particularly the test equipment and special tools used to support the maintenance of the system. Technicians were to list as many types of equipment and tools they felt would be necessary to support the maintenance on the system. The technicians' responses were compared to a list of 28 different generic (as opposed to specific models or manufacturers) types of test and support equipment associated with the AN/TPS-43(E) radar system to gauge how well they could predict support equipment requirements. The responses to this item were not encouraging in terms of either quality or quantity of the responses. Of the 28 types of test and support equipment associated with the system, the AFSC groups identified only from 14 to 17 of these equipment types. Further, the group average response rate for any one of the identified equipment types ranged from 6.3 percent to 21.5 percent, indicating a low response level for this item. Although the technicians were asked to identify the different generic types of equipment, fairly large percentages (80 percent and 52 percent) of two AFSC groups stated that "general support" equipment would be required. It was not possible to interpret these responses accurately since each AFSC group, and probably each individual, had somewhat differing definitions of what constitutes "general support" equipment.

Feedback from Technician Estimators

Effect of Additional Engineering Detail on Maintenance Manpower Estimates. Technicians used the basic engineering data package to make their initial maintenance manpower estimates. They were then given a supplement to the basic engineering data package and instructed to review all their initial estimates, considering the supplemental information as well as the engineering information in the basic package. If they wished to change any estimate based on the supplemental information, they could do so by circling their original estimate and recording their new estimate next to the original. Technicians were also asked what effect the additional information had on their maintenance manpower estimates.

An examination of the questionnaires and the technicians' statements as to the effect of the additional information revealed that only a very few of the estimates were changed as a result of the additional information. Overall, only .73 percent of the estimates made by an AFSC group were changed as a result of the supplemental engineering data. For 22.73 percent of the estimates, technicians reported that the additional information confirmed their original estimates. For the majority of estimates (76.62 percent), however, technicians reported that the additional engineering data neither confirmed nor changed their original estimates. The additional engineering data had virtually no effect on the original maintenance manpower estimates.

Technicians' Confidence in the Estimates. Technicians were also asked to provide a confidence rating of their estimates using a three-point scale. The scale anchors were Little Confidence (1), Confident (2), and Very Confident (3). Overall, the confidence scores for the three career field groups were 1.69, 1.86, 1.89 (Table 15), indicating that the groups were slightly less than confident about their estimates. Looking at the confidence ratings for specific types of estimated data (rows of Table 15), mean confidence ratings ranged from 1.60 (maintenance task time estimates for specific off-equipment tasks) to 2.14 (career field/AFSC estimates).

Information Sources Used to Make Estimates. To gain an insight into what kinds of information technicians used to make their estimates, they were asked to indicate what percent of each estimate was based on their maintenance experience and background and what percent of each estimate was based on the engineering information provided. The resulting percentages for the various types of data estimated and the three AFSC groups are displayed in Table 16. For all types of estimates, technicians depended more heavily on their maintenance background and experience than on the engineering data provided to make the estimates. The data indicate that for all three AFSC groups, 67.4 percent of a given estimate was based on the technicians' previous maintenance experience, while 32.6 percent of a given estimate was based on information the technician obtained from the engineering data package.

Evaluation of Prototype Users Guide

The prototype users guide was reviewed and evaluated by seven manpower experts from the Air Force Maintenance and Supply Management Engineering Team and the Crew Equipment and Human Factors Division of the ASD Directorate of Equipment Engineering at Wright-Patterson AFB. The level of work experience for the individuals ranged from 3 to 20 years, with a mean level of 8.7 years.

The evaluation was designed to generate comments and criticisms in two general areas: the clarity of the guide's instructions and examples and the suggested and potential utility of the expert estimate method.

TABLE 15. TECHNICIANS' RATINGS OF CONFIDENCE IN THEIR MAINTENANCE MANPOWER ESTIMATES

Types of Estimates	Confidence Ratings for AFSC GROUPS			Mean Ratings By Type of Estimate
	303X1	303X2	303X3	
Maintenance Task Times (General) On-Equip	1.81	1.64	1.74	1.73
Off-Equip	1.75	1.58	1.54	1.62
Maintenance Task Times (Specific) On-Equip	1.88	1.72	1.62	1.74
Off-Equip	1.81	1.62	1.38	1.60
Troubleshooting Times	1.75	1.82	1.74	1.77
Troubleshooting Difficulty	1.88	1.94	1.68	1.83
Percentage of Maintenance Actions	1.75	1.77	1.48	1.67
Crew Size	2.06	2.16	1.98	2.07
Skill Level	2.06	2.14	2.04	2.08
Career Field/AFSC	2.25	2.34	1.82	2.14
Training Times	2.00	1.82	1.62	1.81
Support Equipment	1.69	1.60	1.66	1.65
Group Means	1.89	1.86	1.69	
			Overall Mean	1.81

Note: Confidence Rating Scores: 1 = Little Confidence, 2 = Confident, 3 = Very Confident.

TABLE 16. PERCENT OF TECHNICIANS' ESTIMATES BASED ON THEIR MAINTENANCE EXPERIENCE AND ON THE ENGINEERING DATA PROVIDED WITH THE QUESTIONNAIRE

Types of Estimates	Percent of Estimates Based on Maintenance Experience (E) and on Engineering Data (D)						Mean Percent By Type of Estimate	
	303X1		303X2		303X3			
	E	D	E	D	E	D	E	D
Maintenance Task Times (General) On-Equip	67.5	32.5	62.5	37.5	65.9	34.1	65.3	34.7
Off-Equip	71.1	28.9	65.0	35.0	62.2	37.8	66.1	33.9
Maintenance Task Times (Specific) On-Equip	67.9	32.1	65.2	34.8	65.0	35.0	66.0	34.0
Off-Equip	71.4	28.6	59.0	41.0	62.8	37.2	64.4	35.6
Troubleshooting Times	72.5	27.5	55.2	44.8	70.2	29.8	66.0	34.0
Troubleshooting Difficulty	72.9	27.1	55.6	44.4	68.3	31.7	65.6	34.4
Percentage of Maintenance Actions	76.1	23.9	60.6	39.4	62.8	37.2	66.5	33.5
Crew Size	71.8	78.2	70.0	30.0	77.0	23.0	72.9	27.1
Skill Level	75.0	25.0	71.8	28.2	67.4	32.6	71.4	28.6
Career Field/AFSC	71.1	28.9	66.2	33.8	73.7	26.3	70.3	29.7
Training Times	77.9	22.1	64.9	35.1	69.1	30.9	70.6	29.4
Support Equipment	71.2	28.8	52.8	47.2	68.3	31.7	64.1	35.9
Group Means	72.2	27.8	62.5	37.5	67.7	32.3		
						Overall Means	67.4	32.6

In terms of clarity, the areas of the guide causing the most confusion were those describing the adjustments or corrections which could be applied to the estimated data. Specifically, the guide did not adequately describe how the correction factors were determined from the basic studies upon which the recommendations in the guide were based.

Other comments regarding clarity were directed toward the engineering description package and the questionnaire. It was recommended that the engineering description package contain less information on the fundamental theory of system operations (e.g., Doppler theory) and more information on the maintenance environment, the physical location of the components, and steps necessary to access the components. In terms of the questionnaire development, the evaluators cited a lack of guidance for preparing the maintenance scenarios which provide a frame of reference for the task time, person-hour, crew size, and skill level estimates. Specifically, no guidance was offered which indicated how the equipment malfunctions and how the maintenance actions were selected for these scenarios. In general, however, the evaluators felt that the guide contained sufficient information to apply the expert estimate method in the collection of system human resources data.

With regard to the potential application of the expert estimate method, the evaluators agreed that the most appropriate application would be in the early design stages of a system, specifically Milestone 0 and Milestone 1 in the Defense Systems Acquisition Review Process. The major limitation identified, however, was that while the method can be used to estimate maintenance manpower requirements for individual line replaceable units, it does not provide a means of combining these LRU estimates into a systems-level estimate. To accomplish this task, the evaluators indicated that consideration must also be given to the expected operations scenario, maintenance demand, failure rates, and system activity.

The comments from these evaluators were taken into consideration in revising the prototype users guide. Where possible, changes in the guide were made to reflect these comments. The comments also aided in identification of future research direction.

Costs Involved in the Expert Estimate Method

The person-hours spent only on the expert estimate activities of the study were recorded for potential use in predicting the person-hour costs involved in similar applications of the expert estimate method. Where activities were repeated several times during the study, the longest time recorded for these activities, rather than an average time, was used as the basis for predicting

the person-hours. This approach was used to avoid an unrealistically optimistic prediction of the person-hour requirements. Items for which costs could not be stated in terms of person-hours were identified and listed so that they would be included in a cost analysis of a specific application of the expert estimate method. The cost estimates were divided into five areas: Engineering Description Package Development, Questionnaire Development, Expert Estimate Collection, Data Reduction and Analysis, and Report Preparation. Table 17 contains these cost estimates. No other cost data were available to indicate how these predicted costs would vary for a larger-scaled application of the method.

TABLE 17. EXPERT ESTIMATE METHOD COST DATA

Activity	Person-hours
ENGINEERING DESCRIPTION PACKAGE DEVELOPMENT	
Engineering Data Collection:	
Data Collector	80
Proposed System Engineers/Designers	40
Engineering Data Edit	40
Test Reading by Maintenance Technicians	20
Drafting (Artistic Support)	60
Technical Typing/Editing/Reproduction	30
Subtotal:	270
QUESTIONNAIRE DEVELOPMENT	
Selection of Items to be Estimated	40
Draft Sections Following Format Suggestions in Users Guide	40
Technical Typing/Editing/Reproduction	25
Subtotal:	105
COLLECTING EXPERT ESTIMATES	
Select and Locate Expert Estimators	20
Data Collection Visit Scheduling and Coordination	20
Visit Request Preparation	10
On-Site Data Collection (25 Expert Estimators)	
Data Collector Time	20
(Assumptions--4 hours per session, five estimators per session to accommodate daily work scheduling)	

TABLE 17. EXPERT ESTIMATE METHOD COST DATA (concluded)

Activity	Person-hours
Expert Estimator Time	62.5
(Assumptions--1 minute per page of engineering data (25 pages), 1 minute per estimate (95 estimates) plus 20-30 minutes introductory remarks and instructions)	
Supervisor Time for Scheduling Sessions, In- and Out-Briefings, other administrative tasks	5
Subtotal:	137.5
DATA REDUCTION AND ANALYSIS	
Reduction of Raw Data	10
Data Analysis resulting in estimates	30
Subtotal:	40
(Assumptions--25 expert estimators, 95 estimates per individual)	
REPORT PREPARATION	
Report and Briefing Preparation	60
Graphics Support	20
Technical Typing/Editing/Reproduction	25
Subtotal:	105
Also consider travel time, transportation, and per diem if a headquarters out-briefing is required	
Overall Total:	657.5

DISCUSSION

The main objectives of this study were to exercise the expert estimate method, to evaluate the recommendations contained in the prototype users guide, to collect additional evidence of the accuracy of the estimated data, to collect cost data associated with the method, and to evaluate and revise the prototype users guide (Sauer & Askren, 1978b). The utility of the expert estimate method would be determined in large part by the quality of the estimated maintenance manpower data for the ground-based system. The results of this study indicated that the expert estimate method is a potentially useful means of generating maintenance manpower data for new systems.

Prototype Users Guide Recommendations

The recommendations in the users' guide (Sauer & Askren, 1978b) concerning the development of the engineering description package were generally supported in this study. The evaluation of the users guide indicated that more information should be included regarding the location of and access to the various component parts of the system. Recommendations also indicated that less information on general theory of operation need be presented. Informal feedback from the technician estimators also indicated that technicians should review the engineering data package prior to field data collection to ensure that all technical terms are either understood by the technicians or adequately defined within the engineering description package.

The level of detail in the basic engineering description package was similar to engineering description packages used in previous studies (Sauer & Askren, 1978a; Whalen & Askren, 1974). A supplement to the basic engineering description package was prepared to determine the effect of additional engineering data on the quality of the estimates. The fact that the additional detail had virtually no effect on the estimates suggests that there is a point of diminishing returns on the effort spent to collect all possible details of the new system. While it is not possible to state precisely where this point may be for a given system, the engineering description packages used in this and the previous studies can be used as guides to the level of engineering detail necessary. It was also interesting to note that technicians based only 33 percent of each estimate on the engineering data provided. Although no similar previous data were available for comparison, these percentages appear to be reasonable. Technicians would probably rely less on the engineering data and more on their past maintenance experience when making maintenance manpower estimates. It was not possible to determine any relationships between amount of engineering detail and

the degree to which the engineering data are considered in the estimating process. The utility of any such relationships, however, would be questionable, since the amount of engineering detail available in the early design stages of a system is likely to be very limited.

The questionnaire was also developed following the recommendations contained in the prototype users guide. The resulting estimates indicated that the recommendations were generally sound. The superiority of the on-equipment person-hour values for specific tasks, for example, supported the recommendation that the tasks for which person-hour values are to be derived be described in as much detail as possible.

The results of this study generally reinforced the recommendations with regard to the qualifications of the estimators. Technicians were selected from AFSCs within the career field most closely related to the new system. With only a few exceptions, there were no differences among the groups in terms of accuracy of their estimates. In the cases where differences did occur, however, there were no consistent relationships apparent between accurate estimates and group characteristics. This evidence suggests that, while it may be desirable to collect maintenance manpower estimates from technicians with the five-digit AFSC most closely matching the technology of the proposed system, adequate estimates can be made using technicians from the general career field, that is, the first three digits of the AFSC code. This finding indicates that users of the expert estimate method have some flexibility in selecting the technicians who may participate as estimators. This flexibility of selection would be most advantageous when time and financial resources are limited.

The skill level recommendations for technicians used as estimators were not followed exactly. While the majority of the estimators (87 percent) were at least 5-level technicians as recommended, 3-level technicians were asked to participate. Since only nine 3-level technicians participated, however, it was not possible to assess adequately the quality of their estimates. Until more estimate data can be gathered on 3-level technicians, the recommendation that at least 5-level technicians be used as estimators should remain. Support for this statement came from the fact that, given an opportunity to participate as estimators, several 3-level technicians declined to participate on the grounds that their maintenance experience was too limited.

With regard to the quantity of estimators (raters), the prototype guide recommended at least 10 estimators be used. However, if resources permit, 20 estimators should be used to decrease the amount of variability and to increase the accuracy of the estimated data. The person-hour cost data indicated that little in

terms of person-hour resources would be saved by recommending the minimum of 10 estimators. The person-hour costs would increase only 9 percent when increasing the number of estimators from 10 to 25. It would seem that the relatively small increase in cost would be offset by the gains in accuracy and reduced variability (Sauer & Askren, 1978a). The recommended minimum number of estimators can, therefore, be increased to 25, while incurring a relatively small increase in overall cost of the method.

Accuracy of the Estimated Data

The accuracy of the estimated maintenance manpower data items were, of course, the ultimate indicators of the utility of the expert estimate method. The types of data items accurately estimated in this study were crew size, skill level, troubleshooting difficulty, career field/AFSC requirements, training times, and derived estimates of maintenance person-hours. With the exception of career field and training time estimates, the types of data successfully estimated in this study were similar to those successfully estimated in the Sauer & Askren (1978a) study.

Items which were not accurately estimated include percentage of maintenance task occurrences, support equipment requirements, and derived estimates of person-hours for troubleshooting and specific off-equipment tasks. In the case of the troubleshooting person-hour values, the poor accuracy scores may have been due to the AFM 66-1 data rather than to the technicians' inability to estimate data for the derivation of these person-hours. The AFM 66-1 person-hour data for troubleshooting tasks appeared to be unusually high, the result, perhaps, of inexperienced maintenance technicians and unfamiliar maintenance requirements of the new system. Troubleshooting person-hour data reported later in the life of the system may be considerably lower and, therefore, closer to the technicians' estimated person-hours. Person-hour data collected 2 or 3 years from the date of this study may indicate that the technicians' estimates were accurate for a more mature system. Similar results might be found for the specific off-equipment person-hour values and the percent of maintenance task occurrence estimates.

The poor response rate and poor estimates associated with the support equipment requirements question appeared to be at least partially the result of two factors. The support equipment requirements question was placed near the end of the questionnaire. Technicians reached this point after spending approximately 1 1/2 hours on the questionnaire and may have begun to experience boredom or fatigue. Aggravating this potential fatigue factor was the fact that the question was written in an open-end response format. The

technician not only had to organize a potentially lengthy response but was not afforded any types of response cues inherent in a checklist or multiple-choice format. A change of format and physical location within the questionnaire may improve both the response rate and the quality of the responses regarding support equipment requirements.

Cost Data

A direct comparison of the cost of the expert estimate method with another data-generating method was not possible. Aside from the fact that such a comparison was outside the scope of the present study, a comparable data-generating method intended for use in the early design phase of a system could not be identified. However, informal assessments from professionals experienced in the collection of manpower data indicated that the expert estimate method appears to be a low cost and relatively rapid method for collecting these data. It was possible to compare the costs of the various activities which comprise the expert estimate method. The recommendation to use a larger number of estimators was based on such an analysis. However, until a comparison can be made with another data-generating method, the cost data simply stand as a cost record of one particular application of the expert estimate method.

Evaluation and Revision of Prototype Users Guide

Another objective of this study was to revise the prototype users guide based on the experience gained from the application of the expert estimate method and on a critique of the guide itself. The comments generated by the critique were valuable in identifying those areas of the guide which needed clarification, where examples could be used more advantageously, and what types of information should be included in the engineering description package. These comments were taken into account when revising the guide. Comments also indicated that the method, with further development, would be best applied at the Milestone 0 and Milestone 1 decisions in the Defense Systems Acquisition Review Council process. The most valuable comment, however, identified the direction in which this further development of the expert estimate method should proceed. Research and development must be directed toward producing a system-level estimate of maintenance and manpower requirements. Although some of the estimates, such as training time and career field/AFSC, already represent system-level estimates, the task time, person-hour, crew size, and skill level estimates are made at the component or line replaceable unit level. Some method needs to be developed to combine these component estimates in such a way that systems-level estimates can be produced. It should be noted that the method is useful in its present form for trade-off comparisons which do not need to aggregate to a full system estimate. However, with this type of development, the expert estimate method can become a more versatile tool in the early design stages of new systems.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are made based on the findings of this study.

1. The expert estimate method as documented in the prototype users guide (Sauer & Askren, 1978b) was successfully applied to a ground-based radar system to generate estimates of maintenance, manpower, and other types of data.

2. Most of the procedures and recommendations for applying the expert estimate method were supported by both the tryout and the critique of the prototype guide. Changes that were made to the users guide included the adoption of a larger recommended minimum number of estimators (25) and additional guidance regarding preparation of the questionnaire.

3. This application indicated that the expert estimate method can be used to generate estimates of crew size, skill level, career field and Air Force Specialty Code, troubleshooting difficulty, training time, and derived estimates of maintenance person-hours.

4. The expert estimate method has not generated accurate estimates of: percent of maintenance task occurrences, support equipment requirements, and derived estimates of person-hours for troubleshooting and specific off-equipment maintenance tasks.

5. Technicians indicated that 33 percent of any given estimate was based on information in the engineering description package, while 67 percent of any given estimate was based on their maintenance experience.

6. The expert estimate method appears to be a relatively inexpensive and rapid method for generating maintenance manpower data in the early stages of system design. No similar data-generating methods, however, were found for comparison purposes.

7. As an inexpensive means to gain more information on the accuracy of the estimated data, AFM 66-1 maintenance data for the AN/TPS-43(E) radar system should continue to be collected. Twelve months of data collected on either an annual or semi-annual basis could be used to determine how the accuracy of the estimates changes as more maintenance experience is gained with the system.

8. Research needs to be directed toward identifying a method of combining the estimated data at the line replaceable unit level

into system-level estimates. Relevant data items would include task times, crew size, skill level, and person-hours.

9. The expert estimate method should now be applied to an early design stage system analysis to gain further insights into the utility, general applicability, and cost-effectiveness of the method. The validity of the method could also be evaluated when operational data for the system become available and can then be compared to the early design stage estimates.

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GLOSSARY

AFTO Form 349--The title of this form is the "Maintenance Data Collection Record." It is used to record maintenance actions on various types of equipment. The data which may be recorded include: job identification data, component identification data, maintenance task time, crew size, type of maintenance, malfunctions, discrepancies, and specific maintenance actions taken.

Air Force Regulation 39-1--The Airman Classification Regulation defines and describes all Air Force occupational specialties and career fields and their training and skill requirements.

Air Force Manual 66-1--This manual, "Maintenance management policy," establishes the maintenance management system applicable to all Air Force activities engaged in the maintenance of aircraft, missiles, munitions, aerospace ground support equipment, avionics, training equipment, and communications-electronics-meteorological equipment.

Air Force Specialty Code--The Air Force Specialty Code (AFSC) is a five-digit number assigned to Air Force enlisted personnel which defines the general career field and the specialty within the career field in which the individual is qualified and the skill level the individual has attained.

Career Field--Career Field represents a general area of expertise or technology in which an individual is qualified. The first three digits of the Air Force Specialty Code (AFSC) specify the individual's career field. For example, the career field of avionic weapon delivery systems (general area) will include three specialty areas: bomb-navigation systems, defensive fire control systems, and weapon control systems.

Field Training Detachment Training--Field Training Detachments provide job-oriented maintenance training on assigned weapon systems, support systems, and selective equipment. The FTDs require host support in order to provide responsive and quality training.

Off-Equipment Maintenance--Maintenance activities which cannot be accomplished on the system. Maintenance must be accomplished in the maintenance shop.

On-Equipment Maintenance--Maintenance actions which may be performed on the system. No shop maintenance is required.

On-The-Job Training--Training which is accomplished in the course of normal operations or maintenance activities. The trainee learns by observing and/or actually performing real operations or maintenance tasks.

Skill Level--Skill level represents the level of qualification and degree of expertise achieved within a technician's career field and specialty code. The five skill level codes are 1, 3, 5, 7, and 9, with skill level 1 equivalent to a helper, skill level 3 equivalent to an apprentice, skill level 5 equivalent to a specialist, skill level 7 equivalent to a technician, and skill level 9 equivalent to a superintendent. This code appears as the fourth digit of an individual's Air Force Specialty Code (AFSC).

Technical Training--Formal classroom training conducted away from the job site at designated Technical Training Centers.

Work Unit Code--The work unit code is a five-character code used to identify systems, subsystems, and components for which maintenance is required or on which maintenance was accomplished.